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ASPHERIC OPTICAL ELEMENTS PROGRAM

INTERIM TECHNICAL REPORT NO. 14

FOR THE PERIOD 1 OCTOBER 1962 TO 31 DECEMBER 1962

PREPARED BY
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CONTRACT AF 33(600) - 37199
DEPARTMENT OF THE AIR FORCE

BELL & HOWELL COMPANY
7100 McCormick Road
Chicago 45, Illinois

ASPHERIC OPTICAL ELEMENTS PROGRAM

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OBJECT: To develop production manufacturing methods for extremely accurate aspheric lens surfaces.

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Special Project Engineer

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PURPOSE: There is a need to investigate and develop production manufacturing methods for aspheric lens surfaces. In order to achieve the ever-rising quality requirements for photographic objectives, it has become necessary to use aspheric surfaces in the design of lens systems. It has been established that such surfaces will allow for greatly increased quality and at the same time for a reduction in size and weight of the optical system.

The purpose of this contract is to develop equipment and methods for large quantity production of precise aspheric optical elements. Evaluation of the repeated accuracy of manufacturing methods will be accomplished by subjecting the lenses made to careful inspection and by employing them in photographic objectives.

WORK COMPLETED 82% of ENTIRE CONTRACT
100% of PHASE I
100% of PHASE II
70% of PHASE III

(BASED ON CONTRACT SPECIFICATIONS)

ABSTRACT: Major progress, as scheduled, has been made in the finalization of the overall control system. However, progress in the parallel program of lens design and the resulting computor programming reveal that certain changes in the design concept of the translator are required. Also, minor changes in the processing of the A and C pulses are necessary. Briefly stated, the changes are as follows:

1) Actual design of the lenses required by this contract shows that the limit set for the maximum surface slope of one in four is exceeded. Provision will now be made for a maximum surface slope of one in two.

2) It was learned that when the maximum slope capability of the aspheric machine is reached, the next lower slope capability is one-half that of the maximum slope. This is due to the value of the X axis increment, which is determined by the packing density of the A pulses, which in turn control the placement of the command pulses on the B drum. Therefore, it has been decided to increase the number of A pulses by a factor of four.

3) A revision of the concept of the use of the tape control input has been necessitated because of the possibility of accumulating an error in counting down from an integral

number. Decimal overflows would be lost and this error would accumulate at the output of each "B" pulse.

According to the present concept the slope is taken directly from the "word" on the computor tape and successively added to itself. Upon the overflow of a barrier, number one, the decimal remainder is retained in a parallel adding register to become part of the next sum. The slope will be added to itself the number of times indicated by the slope multiplier portion of the "word" and then proceed to the next data "word."

This requires changes in translator logic as well as the addition of an electronic decimal adder.

The three changes herein listed will be explained in detail under their relevant headings. Also, Bell and Howell has developed an automatic aspheric design program which will be explained under the section on "LENS DESIGN."

REVISIONS IN TRANSLATOR AND MACHINE CONTROL LOGIC

The three changes, provision of a maximum slope of one in two, continuity of slope capability, and the elimination of accumulated error in the translator logic are mutually dependent and an overall technical explanation of these items will be given in this section.

Recent experience in lens design has indicated that aspheric elements restricted to a slope of 1/4 or less would be a limitation upon the ability to integrate such aspheric lenses into a spherical system. Thus, in order to provide the maximum advantages of aspheric correction, the slope capability of the aspheric generating machine has been expanded to 1/2.

A simple method has been found for doubling the slope capability for those lenses which require a steeper slope. A two to one (double that of the present X/Y equals four) slope capability can be realized by switching off one of the two heads at the C drum at the proper place in its circuit. Squelching the pulses of one of the two heads at C before it reaches the bidirectional counter has the effect of requiring the Y axis to move twice as far for each B or command pulse and in this manner the slope capability will be doubled.

Since two heads must be used at "C" to distinguish between forward and reverse pulses (Interim Report No. 6, page 24), the squelched pulse circuit will retain that portion of the circuit which feeds the bidirectional counter.

The problem of continuity is solved by the use of an independent 4-times multiplier on the "A" drum.

Consider the fact that the emission of a "B" pulse is triggered on a count of the "A" pulse. This means that if we started with a slope of 1/4, ($y=2.5$ @ $10^{-6}/x=10 \times 10^{-6}$), the next lower slope acceptable to the translator would be 1/8, ($y=2.5 \times 10^{-6}/x=20 \times 10^{-6}$). With the use of an independent 4-times multiplier on the A drum our X increment becomes 2.5×10^{-6} and we can thus add slopes of $1/n$, where n can be any integer.

The multiply-by-four of the "A" pulses does not change the maximum slope capability of the aspheric machine since the packing density of the B pulses cannot exceed those of the original "A" pulses. The maximum slope is still 1/4, or 1/2 if the head on the C drum is switched off.

The placement of four times as many pulses on the A disc would provide continuity, but the packing density would be intolerably increased. The independent "A" pulse multiplier can be provided on a time basis by driving the X axis at a constant speed during the programming of the B pulses. This is accomplished by coupling the shaft of a synchronous motor directly to the shaft of the variable speed motor during the programming cycle. Then for the actual machining of glass, the synchronous motor is disconnected and the variable speed motor takes over.

In order to avoid errors of accumulation, the "B" pulses are now generated by the following method:

The two pieces of information, the slope and the times the slope to be repeated, are transferred to their respective registers where they are stored until the proper number of "A" pulses have satisfied the previously read block of information from the computor tape. Beyond this point the information is processed quite differently.

The previous method of providing "B" pulses was to take the slope and convert it internally into the reciprocal slope and add it to itself until the sum would overflow 1. At the time of overflow, the counter register would clear and a new sum would start forming on the next "A" pulse. The overflow, that is the amount by which the sum exceeded one, would be lost and an error would accumulate at each overflow. Now a binary adding register is provided which will retain the remainder and make it part of the sum that follows.

The data which is to be processed is now read in as a "word" composed of the slope and a slope multiplier (not to be confused with the "multiply-by-four" for the "A" pulses) which states the number of times that the slope is to be added in the adder. This input information remains the same as before; however, with the inclusion of a parallel adding register the slope can be added directly to itself and there is no need to retain the original binary counting circuitry which converted the slope to its complement.

Complete details of the new translator logic follow.

Translator

The lens design data punched on the paper tape by the computor printout contains the following information:

1. Slope
2. Multiplier
3. Sign
4. End of word

This format of the revised system is shown in Figure 1. The slope, which is the ratio of Y or depth of cut to X or radius vector of cut, is expressed in negative binary form. The tape has provisions for handling numbers from 2^{-1} down to 2^{-20}. This data is punched in rows 2, 3, 4, 5 and 6 of channels 2, 3, 4 and 5.

The multiplier is the number of times that a particular slope will be used before a change in slope is required. The system has provisions for handling a multiplication factor of up to 2^{12} times. This data is punched in rows 7, 8, and 9 of channels 2, 3, 4 and 5.

The sign of the slope is stored in row 2 of channel 2. A negative slope is indicated by a "one" or a hole while a positive slope is indicated by a "zero" or a no-hole condition. There will be only one reversal of this slope in any given lens design.

The end of word is indicated by a stop hole punched in row 10 of channel 1. Once started, the tape proceeds past the read heads at a rate of 27 inches per second until it sees a stop code. This signal sets a stop-start binary which, in turn, releases the clutch and sets the brake of the tape reader. This is accomplished with row 10 still in reading position. The end of the program is indicated by two consecutive stop pulses. This causes the reader to shut down and turn on a light indicating "end of program."

The data in row 1 of channel 2 is the signal to initiate carriage return of the printer at the computor on which the lens is designed. Row 1 will then be present only when a carriage return signal is needed. This data is not needed in translation and is shifted out the end of the shift register if it is present and thus ignored.

The complication of reserving an extra code for a carriage return is not inherent to the design of the aspheric generating machine but is the result of the data output of the LGP-30 computors. It will not be necessary to retain this code when the computor programming is done on the IBM machine.

Since the printer cannot print out all "zeros" in a particular row, it becomes necessary to supply an extra channel in which to punch a hole in the event that the data is necessarily all "zeros." Channel 6 is reserved for this purpose.

The logic involved in translation is shown in the block diagram of Figure 2. The object of the translator is to record command pulses for the Y axis on the B drum driven by the X axis as has been explained in Interim Technical Report No. 8 and 13. The glass machining can also be controlled directly from the translator if desired by feeding the B signal output into the command input of the machine. However, this mode of operation would limit the cutting of glass to a single speed, since a synchronous motor is used for driving the X axis during translation.

The punched tape program is loaded into the reader, which is then manually started. The manual start-read button first resets the sign, slope, and reset shift registers and then starts the reader into operation. The data on each channel is read successively by two reading heads spaced one character apart. The signals from the first head are shifted into a comparator and stored. If the readings from the second head compare with that of the first head, they are then shifted into the shift registers by a shift pulse generated from the sprocket holes. The reader then proceeds to the first stop pulse and remains there, awaiting further command.

If the comparator shows a discrepancy between the readings of the two heads, an error signal is generated which is fed back to the automatic stop-read circuit. The reader stops and an error light indicator flashes on, warning the operator of a reading error.

The machine operator now must press the start translate button. In addition to starting the X axis motor control, it also sends a pulse via the "or" gate G1 to reset the sign storage and the slope storage areas. After generating an appropriate time delay through delay 1, this signal becomes a transfer pulse and transfers the sign via "and" gate G5 into the sign storage binary. Simultaneously, it transfers the slope data from the slope shift register into the slope buffer storage area via gate G4 as well as the multiplier data from its shift register into the multiplier counter via gate G3. These transfers take place in the parallel mode.

The complement of the desired data is transferred into the multiplier counter rather than the actual number. By using this technique, the count can serially add to this complement to fill up the counter. By adding one additional pulse artificially generated, the counter will overflow and zero itself, causing a single spillover pulse at the output. This extra one count is obtained by feeding the transfer pulse through delay 2, which allows time for transfer to take place, and then to the +1 input of the counter via "or" gate G2. This same pulse also becomes the reset signal to clear the multiplier, slope, and sign shift registers of their previous data and make them ready to accept the next word.

The reset pulse is then fed into the start input of the automatic stop-start circuit. This starts the reader, which then shifts in the next slope and multiplier with its sign. This start is delayed in time via delay 3 which is the actual mechanical delay of the reader mechanism.

Meanwhile, the X axis drive motor has obtained proper reading speed and turned the A and B2 quantizers until the start pulse from the B2 head opens the "and" gate G6. This start position indicates true center of the cutting tool on the glass and will be the zero reference point. The quantizer pulses from the A disc are triggering pulses to synchronize a multivibrator pulse generator running at four times their rate. This is done for resolution reasons explained earlier in this report. A synchronous motor is used during translation to maintain a more constant output rate of the quantizer pulses.

Upon the opening of gate G6, the first A pulse is applied to gate G7 to become a transfer pulse to enter the slope data from slope storage into the adder. This pulse is also fed into the A input of the multiplier counter via "or" gate G2 to effectively "count down" this multiplier by one digit.

The second A pulse from G6 again transfers the slope data into the adder. It adds this data, by parallel means, to what is already in the adder. It also counts down the multiplier by a second digit. The succeeding A pulses continue to repeat this same operation.

The addition of the slope data, a number never to exceed 0.25, will cause the adder to overflow at the count of 1.0. This spillover or B pulse then goes to the B1 head via the write amplifier and is recorded on the B drum in its proper location with respect to the X axis travel of the carriage. Any remainder which may be generated at the time of overflow is retained in the adder to be carried to the next addition. In the case of controlling the machining of glass directly from the translator, this B pulse will be fed directly into the command input of the machine.

When the multiplier counter spills over, a pulse is fed through gate G1 to recycle the complete operation automatically. When the end of the program is reached, two consecutive stop pulses will indicate end of translation.

The B pulse is also fed into the pre-set counter via gate G8. This gate is controlled through switch S1 by the sign of the slope and must, therefore, be pre-set by the operator before translation begins. The switch S1 connects the circuitry in such a manner as to hold the gate G8 open until there is a change in the sign, then the gate closes to stop the B pulses from entering into the pre-set counter.

Manual pre-set switches in the counter are then selected by the operator to match this count. During the machining of glass, the B pulses will be counted serially and an output signal will be emitted when this pre-set number is reached. The output signal will reverse the direction of the stepping motor controlling the Y axis.

FINAL X AND Y AXES MECHANICAL DRIVE DATA

Table I in this report has been compiled to bring together all the machine control parameters and to bring them up-to-date. Notice that there are revisions in those figures relating to the X axis motor rpm as compared to those given in Interim Technical Report No. 9. This had been brought about by a change in the overall x-axis gear reduction from 3584:1 to 1792:1. The y-axis gear reduction remains at 4032:1.

The A pulses/sec. column also reflects a change in that the figures shown are "translator pulses", i.e., recorded pulses multiplied by four as they are used in translation and as described earlier in this report. Additional information is also given in the table indicating the changes brought about by a desired slope of 2:1 instead of 4:1. Observe that the only parameters affected are those of the Y-axis.

Earlier in this report, mention was made that during translation the X-axis will be driven by an 1800 rpm synchronous motor. The figures shown under the X-axis-linear speed of 10 min/in. most nearly approximate those of translation, since at this linear speed the X-axis motor runs at 1792 rpm.

X-Axis Linear Speed - Min./in.	5	10	15	20
X Lead Screw R.P.M.	2	1	0.667	0.5
X Motor R.P.M.	3548	1792	1195.2	896
A Pulses/Sec.	1344	672	448	336
B & C Pulses/Sec.	366	168	112	84
A Drum Surface Speed - In./Sec.	0.72	0.36	0.24	0.18
B Drum Surface Speed - In./Sec.	0.63	0.31	0.20	0.15
C Drum Surface Speed - In./Sec. - Max.	0.179 0.358*	0.089 0.178*	0.059 0.118*	0.044 0.088*
Y-Axis Linear Speed - Min./In. - Max.	20 10*	40 20*	60 30*	80 40*
Y-Motor Steps/Sec. - Max.	1344 2688*	672 1344*	448 896*	336 672*
Y-Motor R.P.M. - Max.	2016 4032*	1008 2016*	672 1344*	504 1008*
Y-Lead Screw R.P.M. - Max.	0.5 1*	0.25 0.5*	0.166 0.333*	0.125 0.25*

NOTES: 1. All figures shown are for a maximum slope of 4:1, except those containing an asterisk (*), indicating a maximum slope of 2:1.

Table I. MACHINE CONTROL PARAMETERS

LENS DESIGN

The design of the 48" f/4.0 triplet with two or more aspheric surfaces is continuing. In addition to the LGP-30, the IBM-7070 has also been programmed to ray trace through aspheric surfaces and has been made available to further the design work.

A design of high quality has been achieved for monochromatic light. The problems of sphero-chromatism and secondary spectrum are to be solved in the next steps of designing. The present work is concentrated on first achieving control of the sphero-chromatism because its aberrational contributions are greater than those of the secondary spectrum. Once control of the sphero-chromatism is attained the design effort will be directed towards improving the secondary spectrum.

The use of the Bell and Howell aspheric ray trace automatic design program is enabling the study of various glass combinations as well as different power distributions and 3rd order solutions for a specific glass combination.

As indicated in a previous report (#11, 1 April 1961 to 31 March 1962) the design is being treated in two phases, of which the first phase is the design of a lens with low Petzval sums and with control of sphero-chromatism, while the second phase will involve the improvement of the secondary spectrum characteristic with the maintenance of other aberrational corrections. It was estimated that 30 per cent of the total design time will be spent on phase I. Phase I is 40 per cent completed at this time.

RECOMMENDATIONS

The newly developed automatic aspheric design program will be applied to the development of the 48" f/4 optical lens called for in this contract.

The computor results of the 48" f/4 optical design will be compared, through the use of the Bell and Howell design program, with data of existing designs available from Wright Field. This comparison can be made by employing either the LGP-30 or the IBM-7070 computor.

As a result of this program we will be able to explore more thoroughly the systems lending themselves to the correction of secondary spectrum and sphero-chromatism. It is expected that this program will be carried out in part on a 7090 computor.

The contract requires that we prepare blanks which have been processed on the machine and subsequently polished in order to demonstrate the machine capability. The blanks are in rough form in the possession of Bell and Howell. They will be machined to a rough finished form so that they may be mounted on the machine for subsequent processing.

Final design of the translator incorporating the changes required by the new tape input concept will now be completed. Upon completion of the construction of the translator, the system will be tested by the use of synthetic "A" pulses from an audio oscillator. The output pulses from the translator, which represent the "B" pulses on the command drum of the aspheric machine, will be recorded on a magnetic tape recorder. Verification of reliable function of the translator can then be obtained by observing the count of "A" and "B" pulses by the use of an electronic counter.

Packaging of the electronic controls for the aspheric machine will continue simultaneously with the work on the translator. Each area of the control system will be thoroughly tested by attaching it to the aspheric machine itself and will be evaluated under conditions of its final environment.

Safety stops, both electrical and mechanical, have been designed for limits of travel for the X and Y carriages and will be installed before either carriage is put into motion by the various areas of electronic control.

A list of possible errors in the generation of aspheric surfaces due to variations in temperature, whether due to the overall room ambient or due to various local heat generators, has been compiled. Whereas no serious complications are expected from ambient temperature variations, the possible trouble areas will be studied just as soon as each area of the machine is operable.

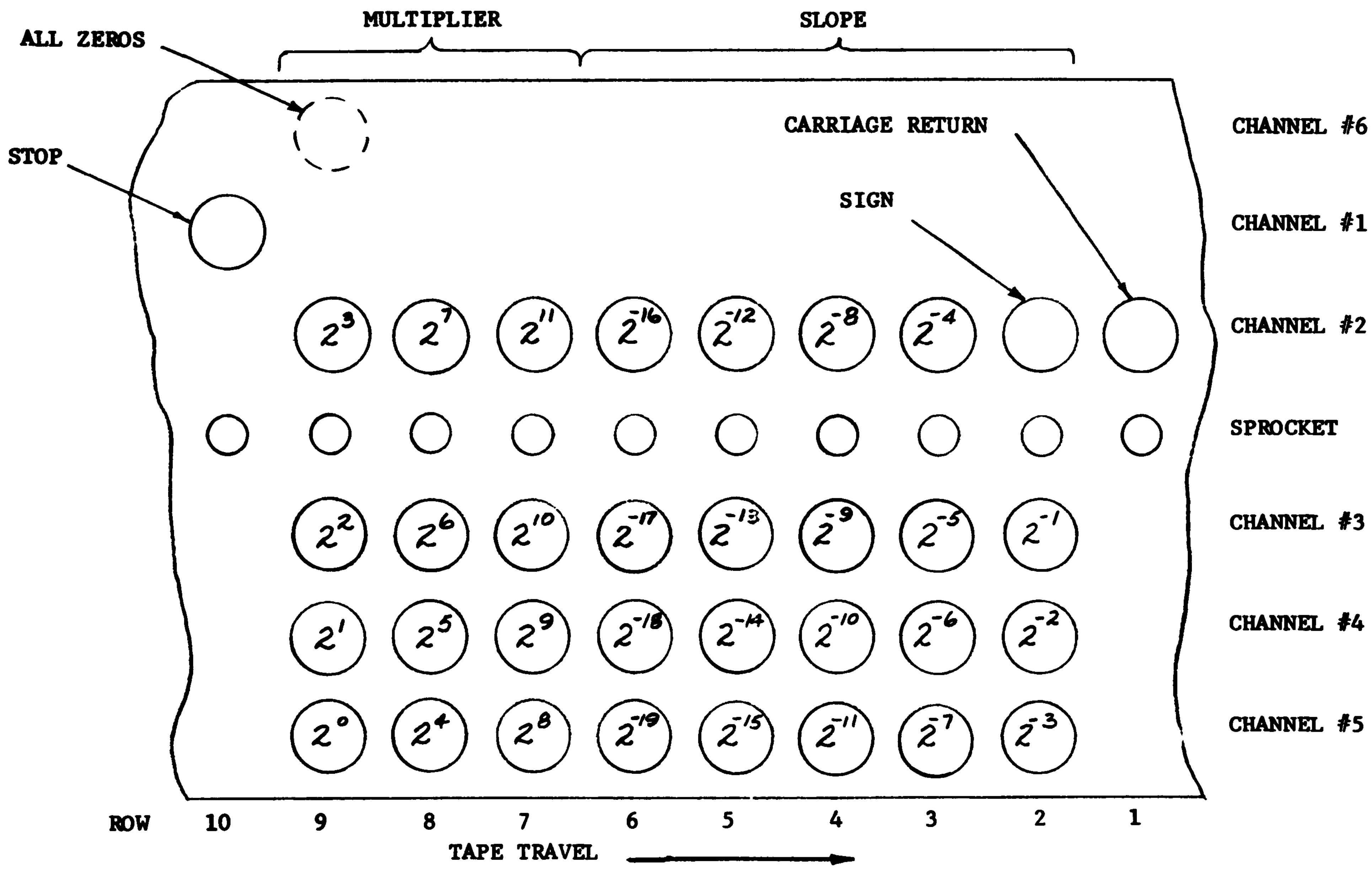

FIGURE 1 TAPE FORMAT

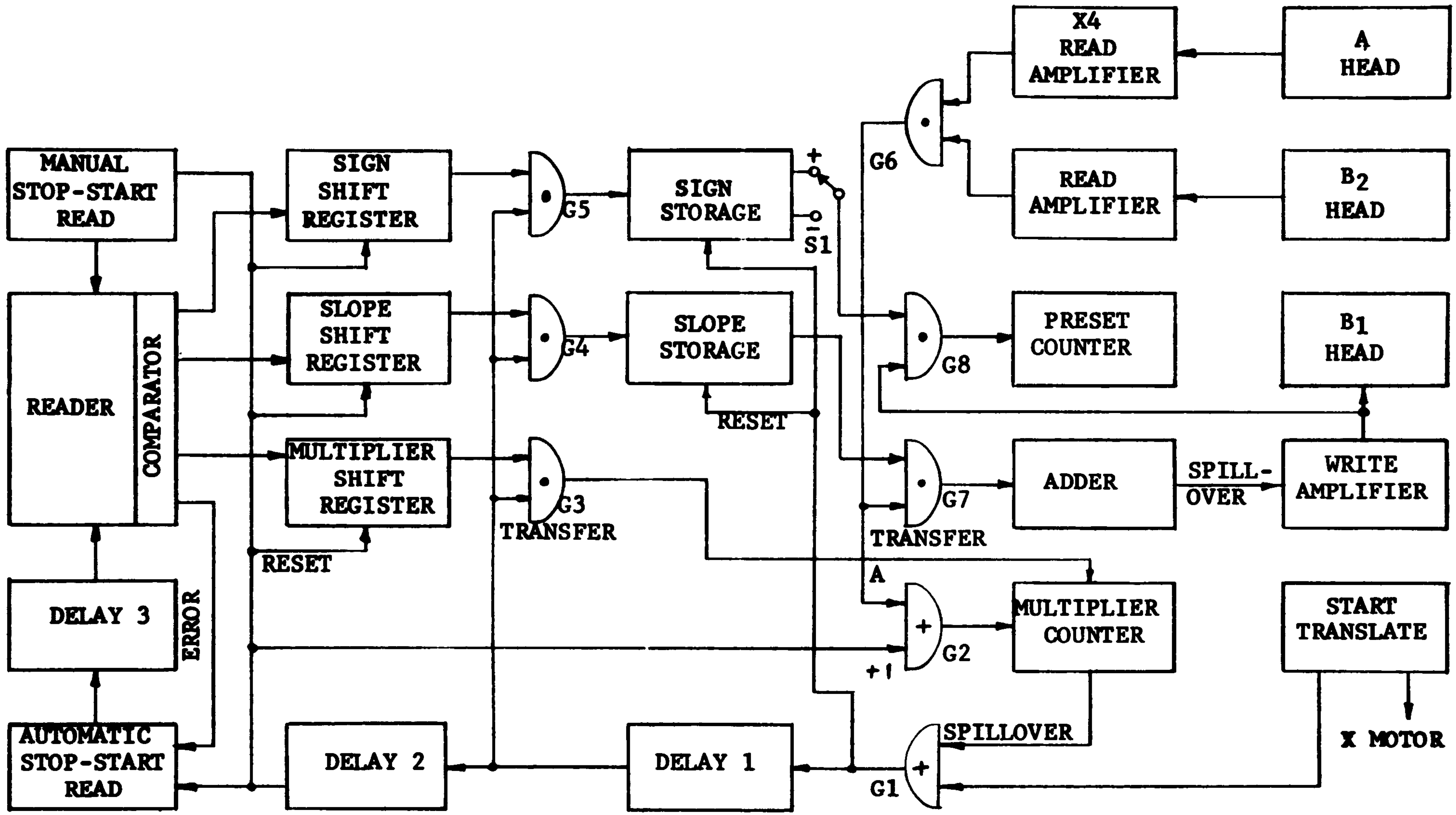

FIGURE 2 - TRANSLATOR BLOCK DIAGRAM

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